X 64 17206

[redacted]

NASA TECHNICAL MEMORANDUM

NASA TM X-981

NASA TM X-981

CLASSIFICATION CHANGED

UNCLASSIFIED

TO NASA TD

By Authority of 72-235 Date 8 JUN 1972

CASE FILE COPY

Declassified by authority of NASA
Classification Change Notices No.
Dated ** 3 0 SEP 1972

STABILITY AND CONTROL CHARACTERISTICS OF A FLAT-BOTTOM LIFTING REENTRY CONFIGURATION AT A MACH NUMBER OF 1.61

by H. Norman Silvers and Jerry L. Lowery

Langley Research Center

Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • OCTOBER 1964

[redacted]

[redacted]

STABILITY AND CONTROL CHARACTERISTICS OF A FLAT-BOTTOM LIFTING REENTRY CONFIGURATION AT A MACH NUMBER OF 1.61

By H. Norman Silvers and Jerry L. Lowery

Langley Research Center
Langley Station, Hampton, Va.

GROUP 4
Downgraded at 3 year intervals;
declassified after 12 years

CLASSIFIED DOCUMENT—TITLE UNCLASSIFIED
This material contains information affecting the national defense of the United States within the meaning of the espionage laws, Title 18, U.S.C., Secs. 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law.

NOTICE
This document should not be returned after it has satisfied your requirements. It may be disposed of in accordance with your local security regulations or the appropriate provisions of the Industrial Security Manual for Safeguarding Classified Information.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

[redacted]

STABILITY AND CONTROL CHARACTERISTICS OF A FLAT-BOTTOM LIFTING REENTRY CONFIGURATION AT A MACH NUMBER OF 1.61*

By H. Norman Silvers and Jerry L. Lowery
Langley Research Center

SUMMARY

An investigation has been made in the Langley 4- by 4-foot supersonic pressure tunnel to determine the longitudinal and lateral stability and control characteristics of a flat-bottom reentry configuration at a Mach number of 1.61. The results of the investigation indicated that the vehicle had what were considered inadequate longitudinal handling qualities due to the limited up-elevator control available for maneuvers above the trim angle of attack, coupled with low effectiveness of the upper-surface control flap, and the pitch-up shown by the configuration at high angle of attack. A significant part of the available up-elevator was required to trim the vehicle within the operational range of angle of attack (16° to 26°). The maximum lift-drag ratio was about 1.4 and did not vary appreciably from 16° to the highest test angle (26.2°).

The configuration was directionally unstable in the operational angle-of-attack range but had relatively high effective dihedral. Deflection of the rudders at opposite angles (toeing) with trailing edge outward was an effective way to increase the directional stability with little change in the effective dihedral.

INTRODUCTION

Configurations having moderately high lift-drag ratios (on the order of 1.5) are of considerable interest for future space vehicles due in part to their terminal range adjustment ability. To realize the advantages of terminal range adjustment demands acceptable aerodynamic stability and controllability of the vehicle. The present investigation was made to determine these characteristics at a Mach number of 1.61 over an angle-of-attack range from about -4° to about 26°. The configuration tested was a version of a basic form known as the SV-5, which is typical in many respects of a large number of reentry configurations having moderate lift-drag ratios presently being studied.

---

*Title, Unclassified.

SYMBOLS

The results are presented as force and moment coefficients with lift, drag, and pitching moment referred to the stability axis system and rolling moment, yawing moment, and side force referred to the body axis system. The reference center of moments was at a location of 54.6 percent body length aft of the nose, and at 40 percent of the maximum height above the body reference line.

The values of reference span and area used to obtain coefficients are the values for the present configuration without tip-mounted fins. The reference length is somewhat less than the true length with true length being shown in parentheses in the following definitions:

b — body reference span, 0.460 ft

$\bar{c}$ — body reference length, 1.058 (1.106) ft

C_D — drag coefficient, $\frac{\text{Drag}}{qS}$

C_L — lift coefficient, $\frac{\text{Lift}}{qS}$

C_l — rolling-moment coefficient, $\frac{\text{Rolling moment}}{qSb}$

C_m — pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS\bar{c}}$

C_n — yawing-moment coefficient, $\frac{\text{Yawing moment}}{qSb}$

C_Y — side-force coefficient, $\frac{\text{Side force}}{qS}$

D — drag

L — lift

L/D — lift-drag ratio, $\frac{C_L}{C_D}$

q — free-stream dynamic pressure, lb/sq ft

S — projected reference planform area, 0.343 sq ft

α — angle of attack referred to body reference line, deg

β — angle of sideslip referred to plane of symmetry, deg

C_{n_β} directional-stability parameter, $\frac{\partial C_n}{\partial \beta}$

C_{l_β} effective-dihedral parameter, $\frac{\partial C_l}{\partial \beta}$

C_{Y_β} side-force parameter, $\frac{\partial C_Y}{\partial \beta}$

δ_e resultant angle of longitudinal control flap, $\left(\frac{\delta_{right} + \delta_{left}}{2}\right)_{upper}$ and $\left(\frac{\delta_{right} + \delta_{left}}{2}\right)_{lower}$, positive deflection is trailing edge down, deg

δ_a resultant angle of roll-control flap, $\left(\delta_{right} - \delta_{left}\right)_{upper}$ and $\left(\delta_{right} - \delta_{left}\right)_{lower}$, positive deflection generates negative rolling moment, deg

δ_r deflection of rudder control, positive when trailing edge is deflected left, deg

left, right denote control flap lateral location with respect to plane of symmetry when viewed from rear

upper, lower denote control flap vertical location when viewed from rear

Model component notation:

B body

C canopy

F tip-mounted vertical fins

F_c vertical fin mounted in plane of symmetry

F_v ventral fins mounted below tip fins

MODEL AND APPARATUS

A photograph of the model is shown in figure 1. Details of the model and configuration identification are presented in figure 2.

The model has a leading-edge sweep angle of 77° with large radii nose and leading-edge contour. The cross section has a semielliptic top and a nearly flat lower surface. Vertical stabilizing surfaces were attached to the outboard tips of the body with full fairings between the body and tip fins.

Vertical stabilizing surfaces consisted of two fins located at the tips of the body planform and having 16° of roll orientation from the vertical; a center fin on the plane of symmetry having a planform identical to the projected side planform of the tip fins; and ventral fins located below the tip fins with a chord plane parallel to the plane of symmetry.

The model was equipped with flap controls for longitudinal and directional control. The longitudinal control flaps or elevators were located in pairs at the trailing edge of both the upper and lower surface (fig. 2). Roll control was investigated by differential positioning of the longitudinal control flaps. The directional control flaps or rudders were also investigated as a pair and were located at the trailing edge of the tip fins.

TEST CONDITIONS

The test conditions are summarized in the following table:

Mach number	1.61
Stagnation temperature, $^{\circ}$F	100
Stagnation pressure, lb/sq ft abs	1,510
Reynolds number based on reference length of body	3.17×10^{6}

The stagnation dewpoint was maintained sufficiently low (-25° F or lower) so that no condensation effects were encountered in the test section. The angle of attack was corrected for deflection of the balance and sting under load. The Mach number variation in the test section was approximately ± 0.01 and the flow-angle variation in the vertical and horizontal planes did not exceed about $\pm 0.1^{\circ}$. The axial force was not adjusted to a base pressure equal to free-stream static pressure.

Force measurements were made through the use of a six-component internal strain-gage balance. The model was mounted in the tunnel on a remotely controllable rotary-type sting. The angle-of-attack range of the test extended from about -4° to about 26°. Angles of sideslip of 0°, 2.5°, and 5° were used to obtain the lateral stability results through the angle-of-attack range. Determination of the lateral stability parameters was made from these runs subsequent to the reduction of data and the resulting values are presented herein.

The estimated maximum variations in the individual measured quantities are as follows:

C_L	±0.01
C_D	±0.001
C_m	±0.004
C_n	±0.001
C_l	±0.001
C_Y	±0.002

RESULTS AND DISCUSSION

Longitudinal Characteristics

The longitudinal characteristics of the basic configuration $BCFF_c$ resulting from deflection of the upper-surface control as an elevator are shown in figure 3. The results show that with the existing stability level, 30° to 35° of deflection is required for trim over the expected operational angle-of-attack range (16° to 26°). The pitching moment due to the remaining 5° to 10° of up-elevator does not appear adequate to provide nose-up attitude adjustments required by vehicle range or maneuver considerations or longitudinal retrim where differential flap deflections are necessary for roll control. This condition may be alleviated by cambering the body to introduce positive pitching moment at zero lift. The results also indicate that the configuration has an unstable break in the pitching-moment curve and becomes seriously unstable at the higher angle of attack. Such instability, referred to as pitch-up, causes dual trim angles of attack to occur. Pitch-up, coupled with low stability at low angles of attack and low control effectiveness of the upper-surface flaps at all angles of attack, results in a configuration considered to have unsafe handling qualities.

The results (fig. 4) show good lower flap effectiveness at low angles of attack and increases in effectiveness as angle of attack increases. Deflection of the lower-surface control is of interest when nose-down excursions in attitude from trim at high angles of attack are required and particularly when return to high angle trim is anticipated. In this mode of operation, the lower flaps would act as a vernier control while the upper flaps remain in the near-fully-deflected condition required for high angle trim.

The maximum lift-drag ratio of the configuration with $\delta_e = 0^\circ$ is about 1.4 and does not vary appreciably within the angle-of-attack range from 16° to the maximum test angle (26.2°). At the lower angles of attack, deflection of the upper controls reduces the lift-drag ratio and deflection of the lower controls increases the lift-drag ratio. In the higher angle-of-attack range, there is no appreciable effect of control deflection on the lift-drag ratio.

The effects of various components of the model on the longitudinal aerodynamic characteristics are shown in figure 5. The results were obtained with an up-deflection of the upper-surface control of 30° which best represented trim throughout the angle-of-attack range of interest. Although the tip-mounted ventral fins F_V have a beneficial stabilizing effect at the higher angles of attack, they cannot be considered a permanent component of the configuration because of thermal considerations at hypersonic velocities. The results further indicate that the tip or main vertical stabilizing surfaces F are longitudinally stabilizing but aggravate the pitch-up condition at the higher angles of attack.

Lateral Characteristics

Roll control is obtained by differential deflection of the same trailing-edge flaps that are used for longitudinal control. The longitudinal effects of differential flap deflection (fig. 6) show that interference does not have a large effect on the longitudinal trim characteristics in that the average of two differential deflection angles has approximately the same stability and trim characteristics as the equally deflected flaps. Although roll effectiveness appears adequate (fig. 7), the problem indicated by the longitudinal characteristics in combination with the roll characteristics is one of longitudinal trim. When roll is obtained by either deflecting a single lower flap downward or reducing the up-deflection of an upper flap, a nose-down pitching moment will result that cannot be controlled by the available upper-surface controls.

The lateral stability results (fig. 8) show that the basic configuration is directionally unstable at high angles of attack. However, the configuration does have high effective dihedral which compensates in a measure for the directional instability. The addition of ventral fins makes the configuration directionally stable and reduces the effective dihedral. As previously noted, however, ventral fins cannot be considered a permanent component of the configuration. The results also show (fig. 8) that the canopy produces a decrement in directional stability throughout the angle-of-attack range. The effect of the center vertical fin is stabilizing as expected at the lowest angles of attack but destabilizing at the higher angles of attack. The high angle-of-attack instability is probably due to a vortex caused by detached flow on the upper surface of the model.

The use of opposite deflection of twin rudders, referred to as toed rudders, is an effective means of improving directional stability at supersonic and hypersonic speeds. The effect of toed rudders on the lateral stability parameters is presented in figure 9. The results show the increase in directional stability expected. Approximately 10° of rudder toeing is required to achieve neutral directional stability at high angles of attack. Toe angles up to 20° show an increasing beneficial effect. Additional rudder toe beyond 20° does not significantly increase the directional stability. Rudder toe does not change the effective dihedral of the configuration.

It is to be noted (fig. 10) that toeing the rudders introduces a negative pitching-moment increment which has previously been pointed out as a serious problem with limited available up-control for longitudinal trim.

The rudder control effectiveness (fig. 11) is high with about 5° of rudder deflection being required to trim the unstable yawing moment of the configuration $BCFF_c$ at 10° of sideslip. (See fig. 8.) On the other hand, the roll due to rudder deflection is also high. The utilization of differential elevator deflection for roll control compensation would, of course, indirectly lead to additional constraints on high angle-of-attack longitudinal trim.

CONCLUSIONS

An investigation has been made in the Langley 4- by 4-foot supersonic pressure tunnel of the longitudinal and lateral stability and control characteristics of a flat-bottom lifting reentry configuration at a Mach number of 1.61. The results of the investigation indicate the following conclusions:

1. The configuration was not considered to have adequate longitudinal handling qualities due to pitch-up within the operational angle-of-attack range and low effectiveness of the upper-surface control flap.

2. A significant part (30° to 35°) of the 40° available up-elevator was required to trim the vehicle within the operational range of angle of attack (16° to 26°).

3. The maximum lift-drag ratio was about 1.4 with undeflected elevators and did not vary appreciably from 16° to the highest test angle of attack (26.2°).

4. Roll-control effectiveness appeared adequate, but if a rolling moment is to be obtained, a reduction in effective up-elevator deflection is required so that the longitudinal trim capability at high angles of attack is further limited.

5. The configuration was directionally unstable at high angles of attack but had comparatively high effective dihedral which may result in a configuration with adequate lateral stability characteristics.

6. The use of opposite rudder deflection on each tip control, referred to as toed rudders, was an effective means of increasing the directional stability with 10° of deflection eliminating the directional instability at high angles of attack.

7. The effectiveness of the rudders was high and contributes a large amount of rolling moment when deflected.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., January 7, 1964.

Figure 1.- Model mounted in the test section of the tunnel.

L-63-2899

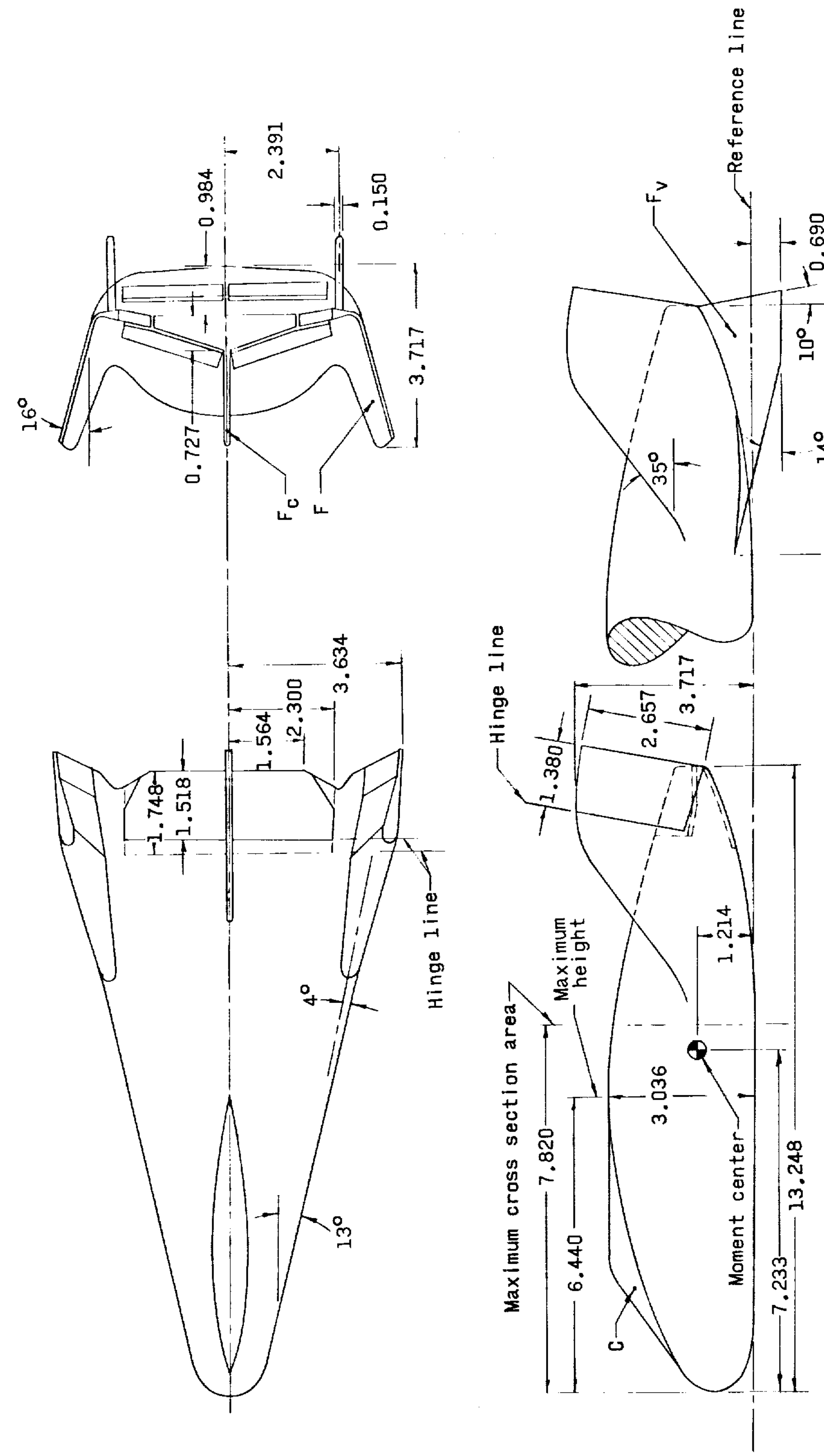


Figure 2.- Drawing of the test model. (All dimensions are in inches unless otherwise indicated.)

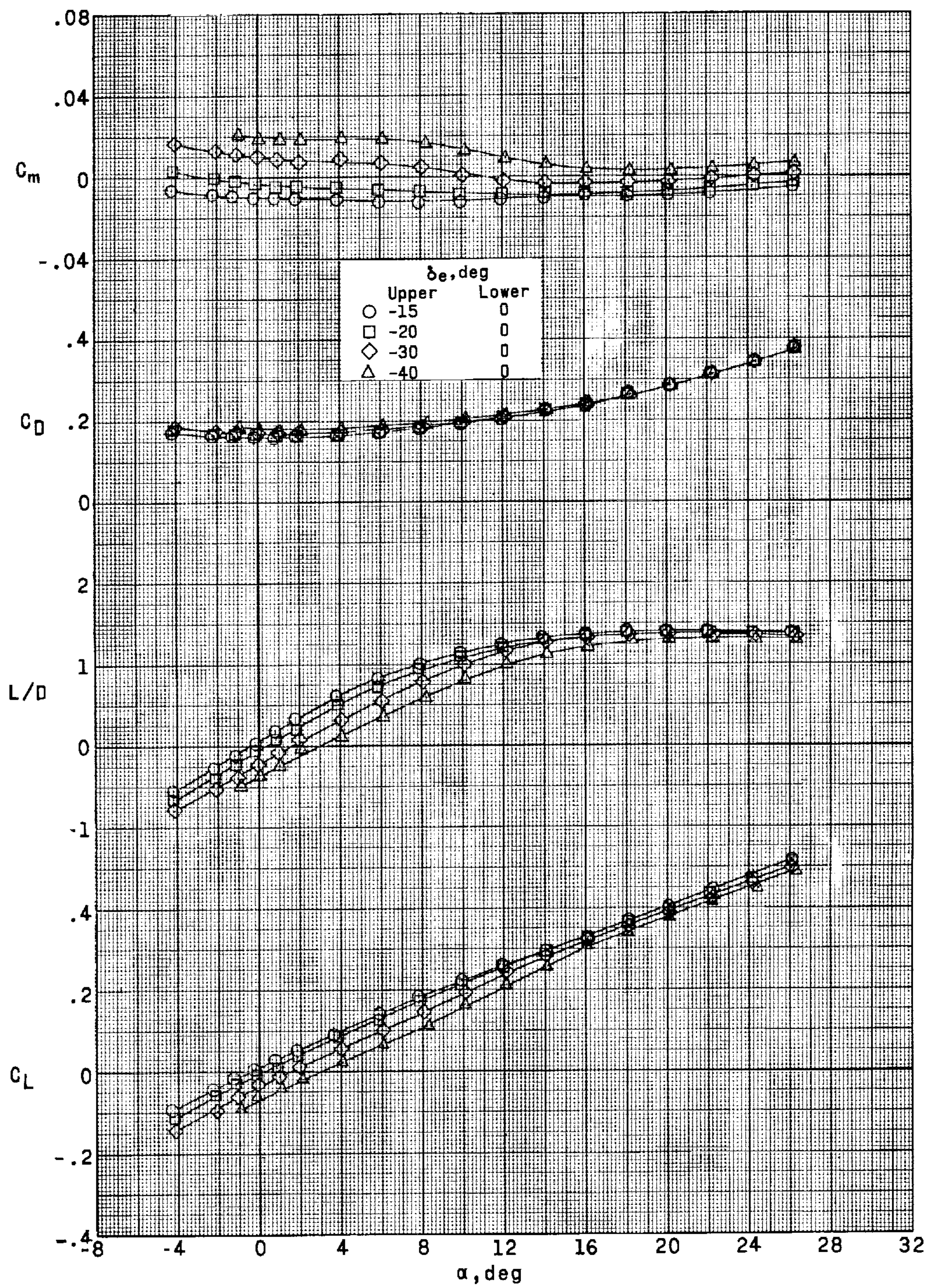
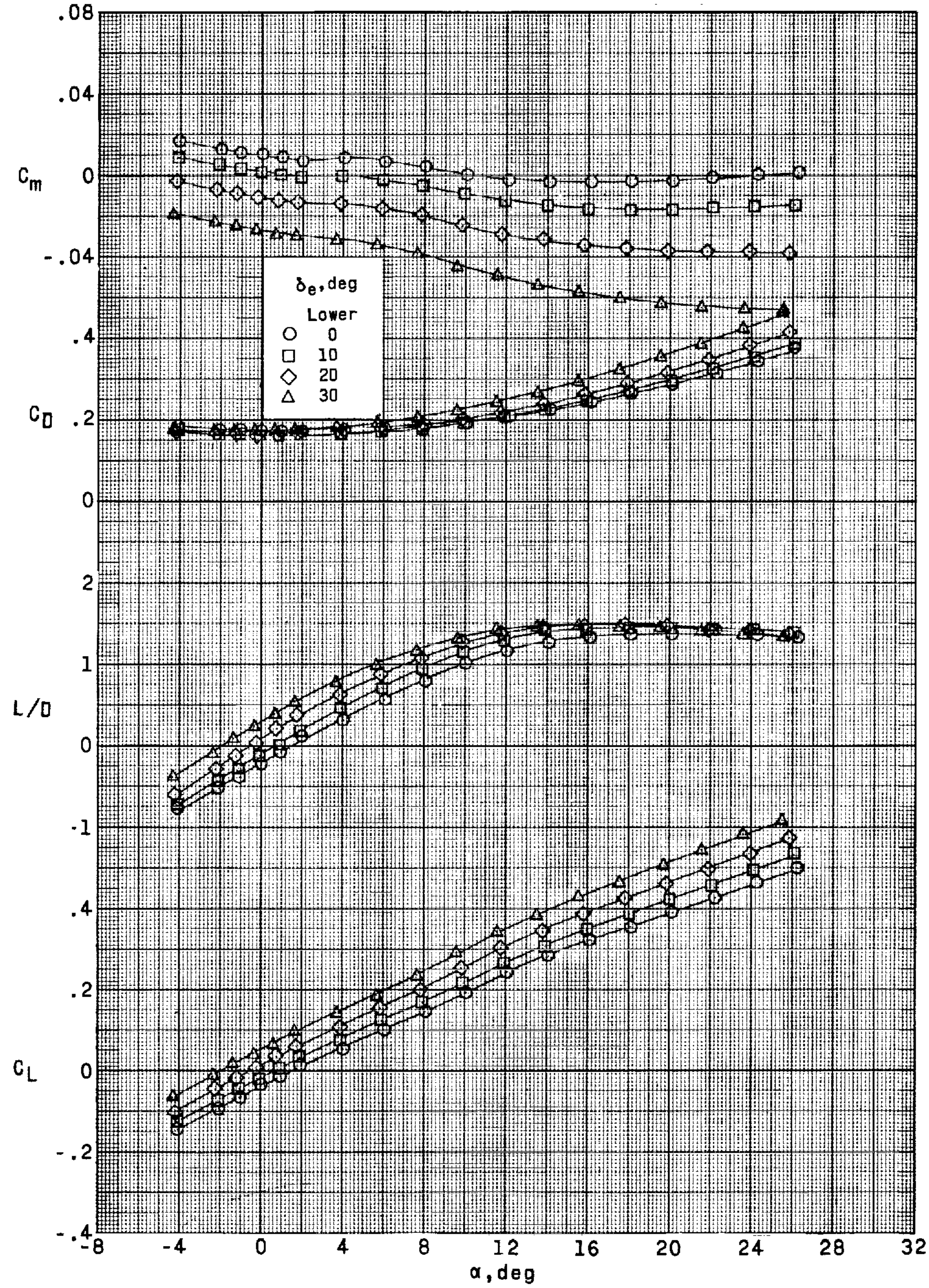
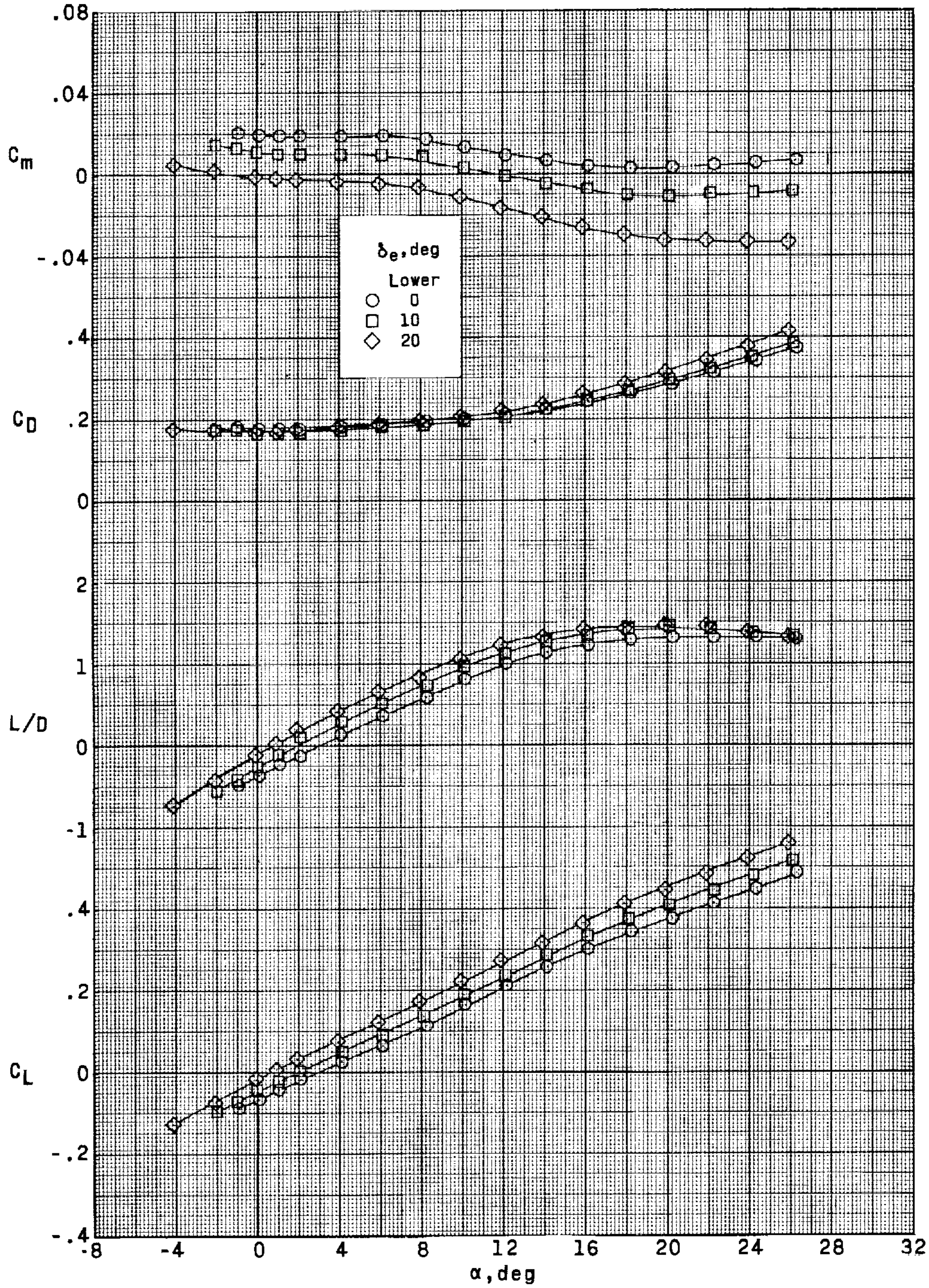


Figure 3.- Aerodynamic characteristics in pitch of the model with various deflections of the upper surface pitch control; configuration $BCFF_c$.



(a) $\delta_{e_{upper}} = -30^{\circ}$.

Figure 4.- Aerodynamic characteristics in pitch of the model with various deflections of the lower pitch control; configuration $BCFF_c$.



(b) $\delta_{e_{upper}} = -40^{\circ}$.

Figure 4.- Concluded.

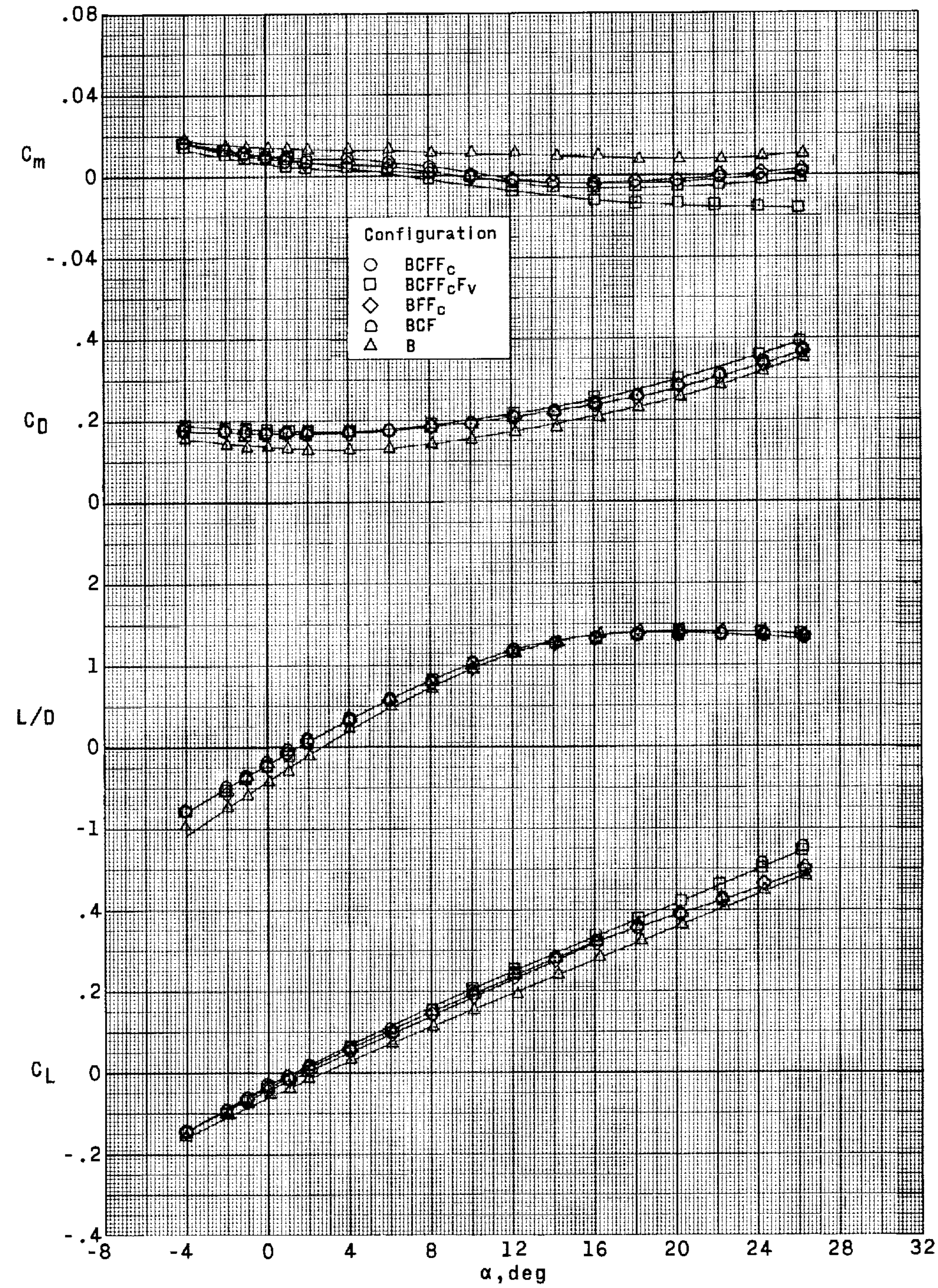


Figure 5.- Effect of various components of the model on the aerodynamic characteristics in pitch; $\delta_{e_{upper}} = -30^\circ$; $\delta_{e_{lower}} = 0^\circ$.

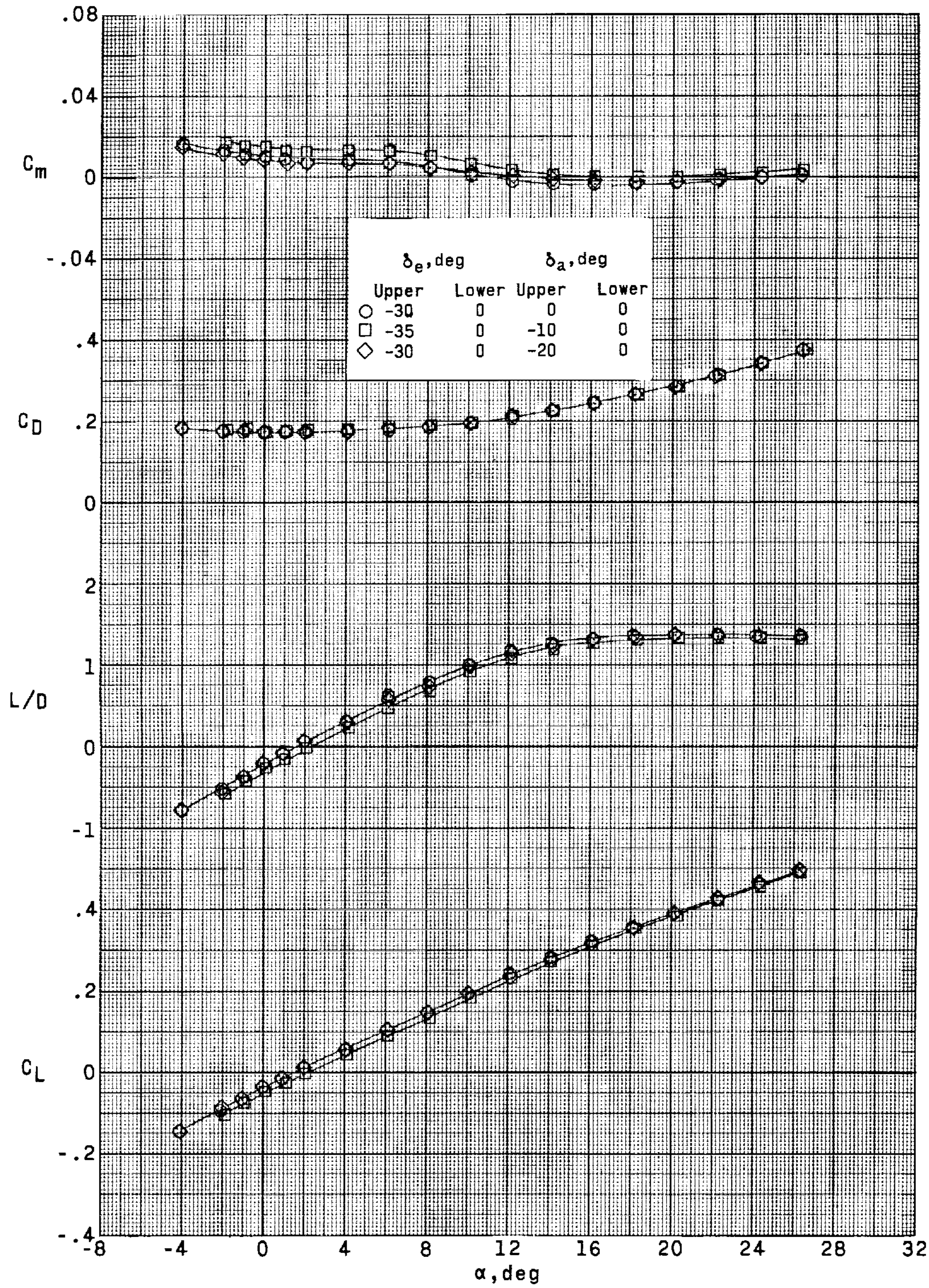


Figure 6.- Aerodynamic characteristics in pitch of the model with various differential deflections of the pitch flaps for roll control; configuration $BCFF_c$.

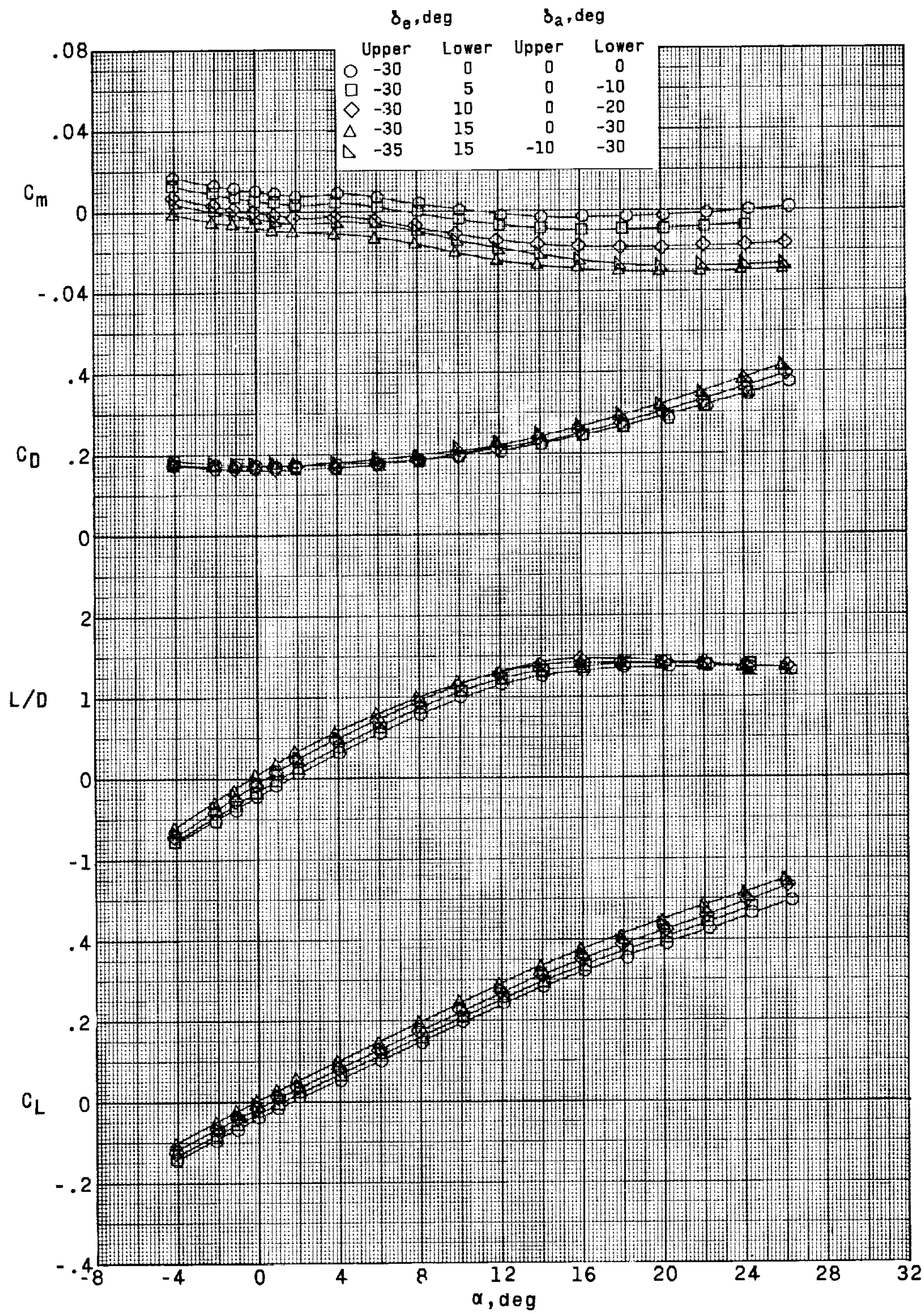


Figure 6.- Continued.

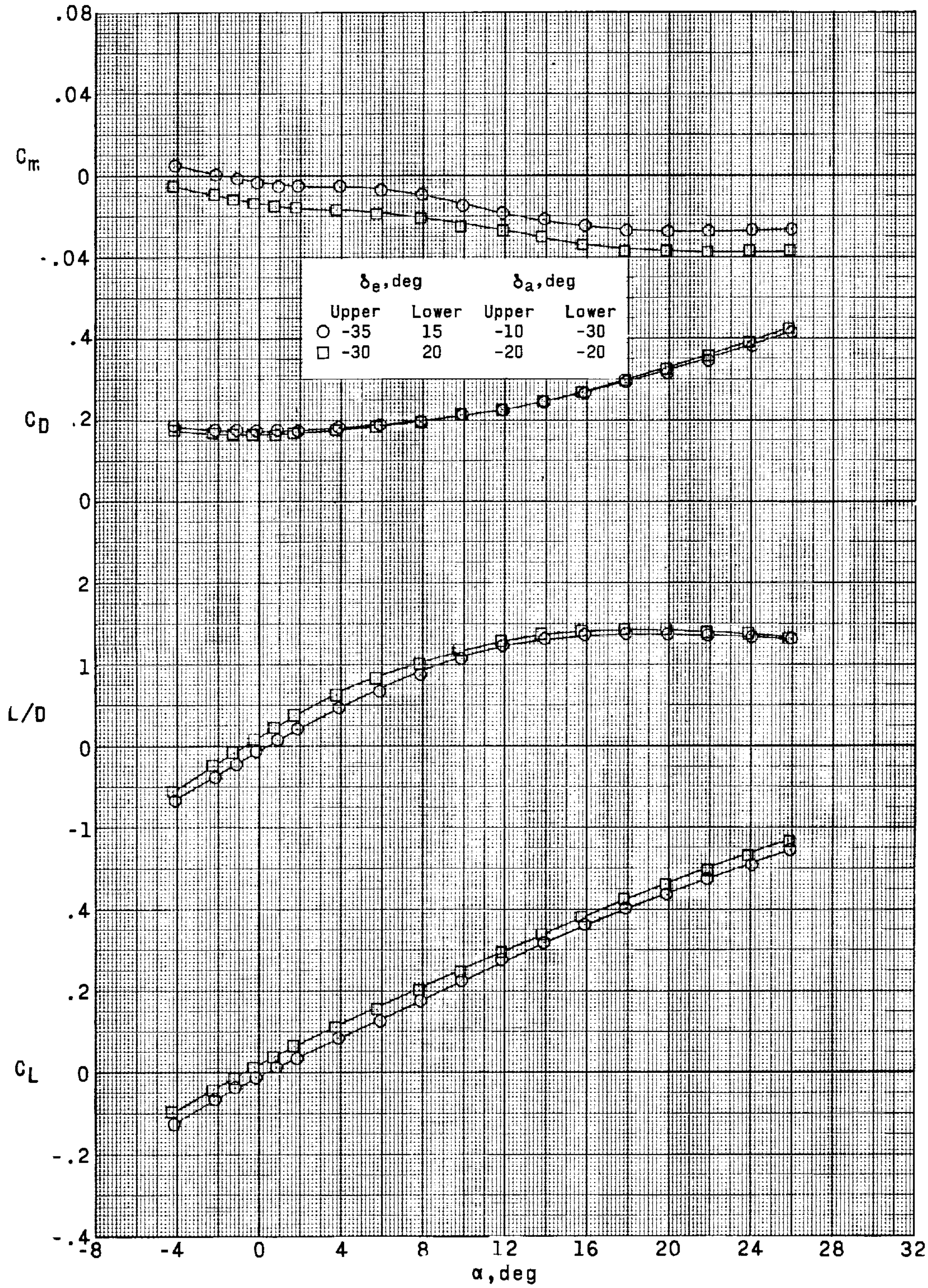


Figure 6.- Concluded.

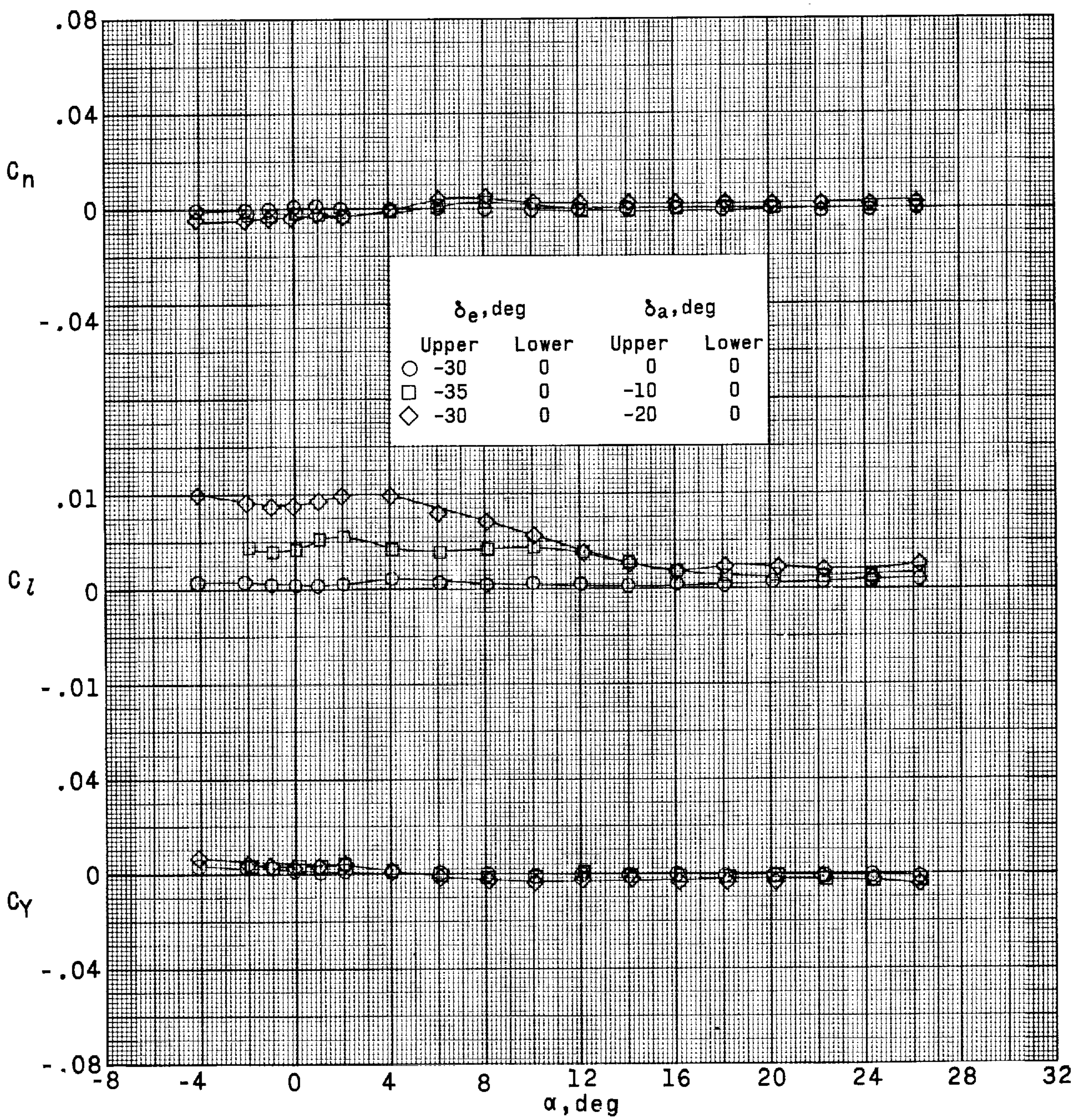


Figure 7.- Lateral aerodynamic characteristics of the model with various differential deflections of the pitch flaps for roll control; configuration $BCFF_c$.

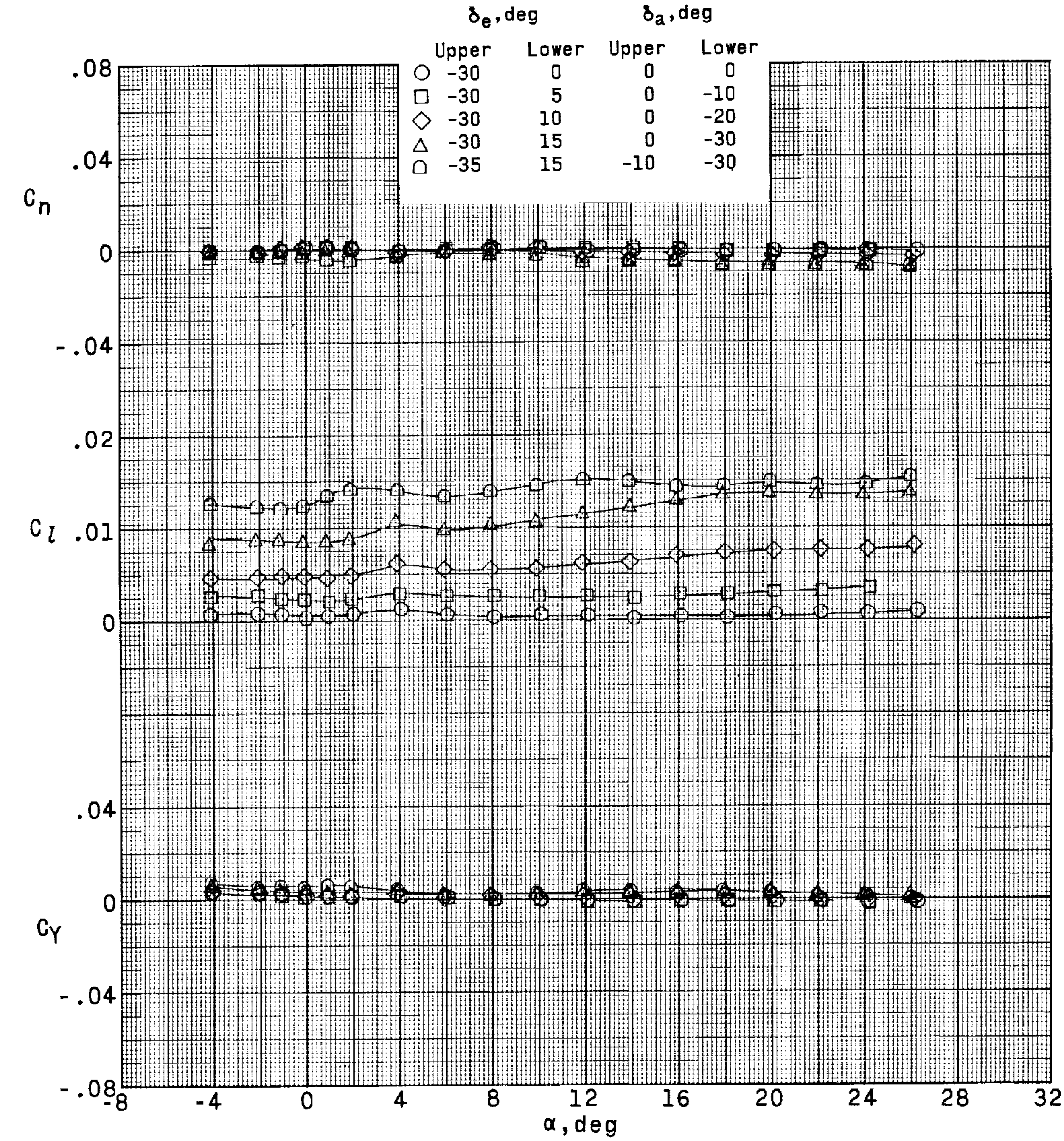


Figure 7.- Continued.

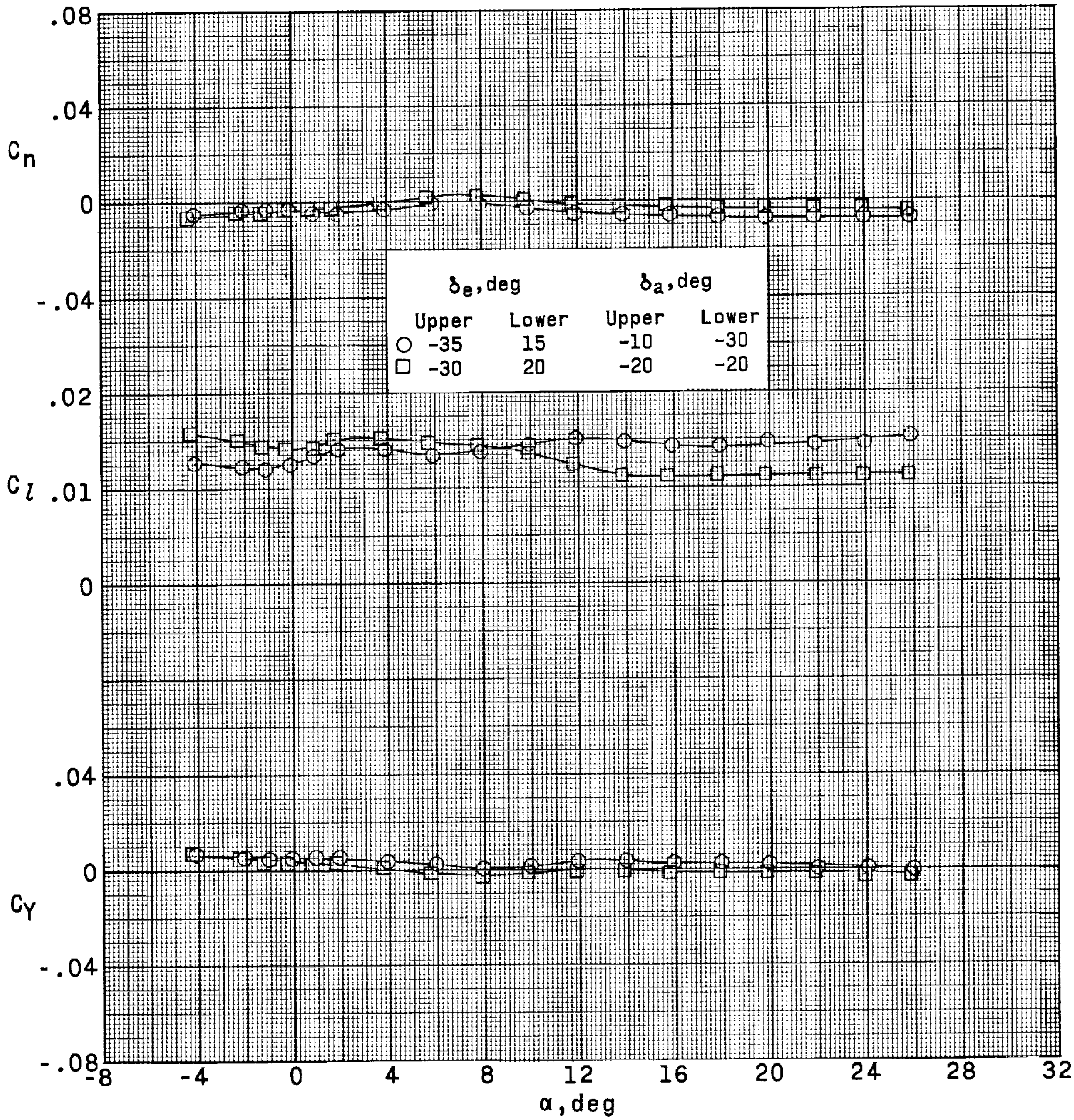


Figure 7.- Concluded.

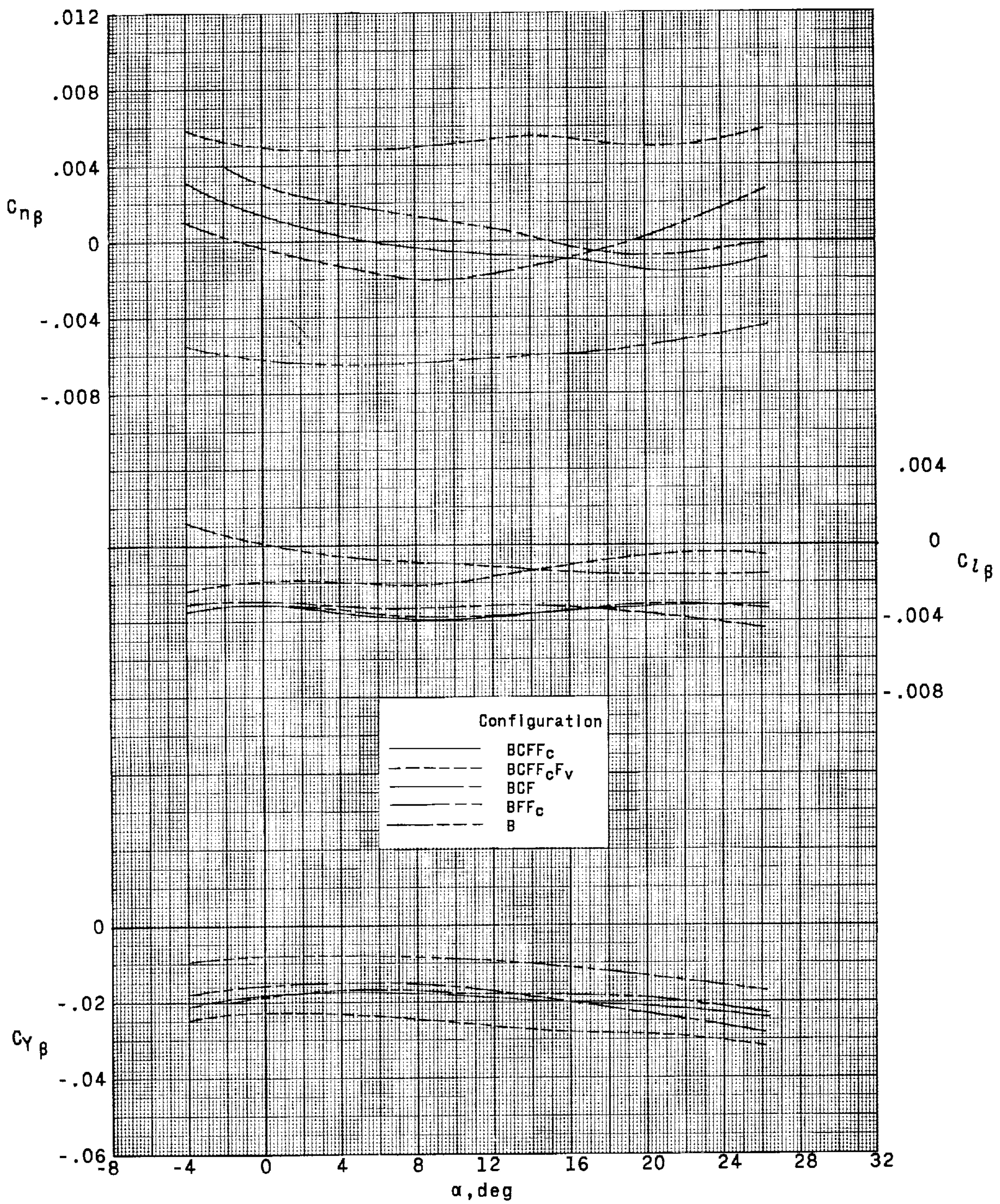


Figure 8.- Effect of various components of the model on the lateral stability characteristics of the model; $\delta_{e_{upper}} = -30^\circ$.

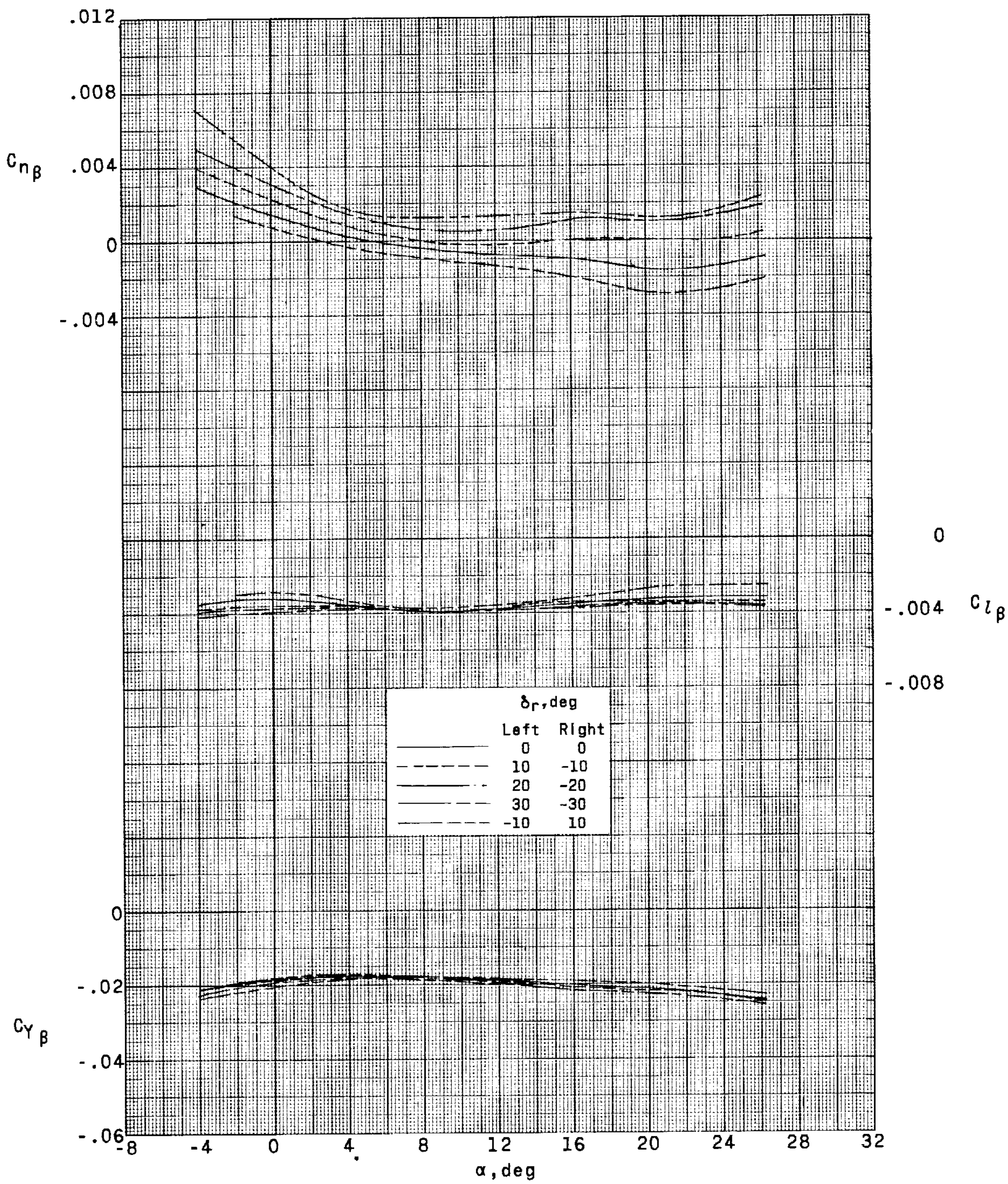


Figure 9.- Effect of toed rudders on the lateral stability characteristics of the model; configuration $BCFF_c$; $\delta_{e_{upper}} = -30^{\circ}$; $\delta_{e_{lower}} = 0^{\circ}$.

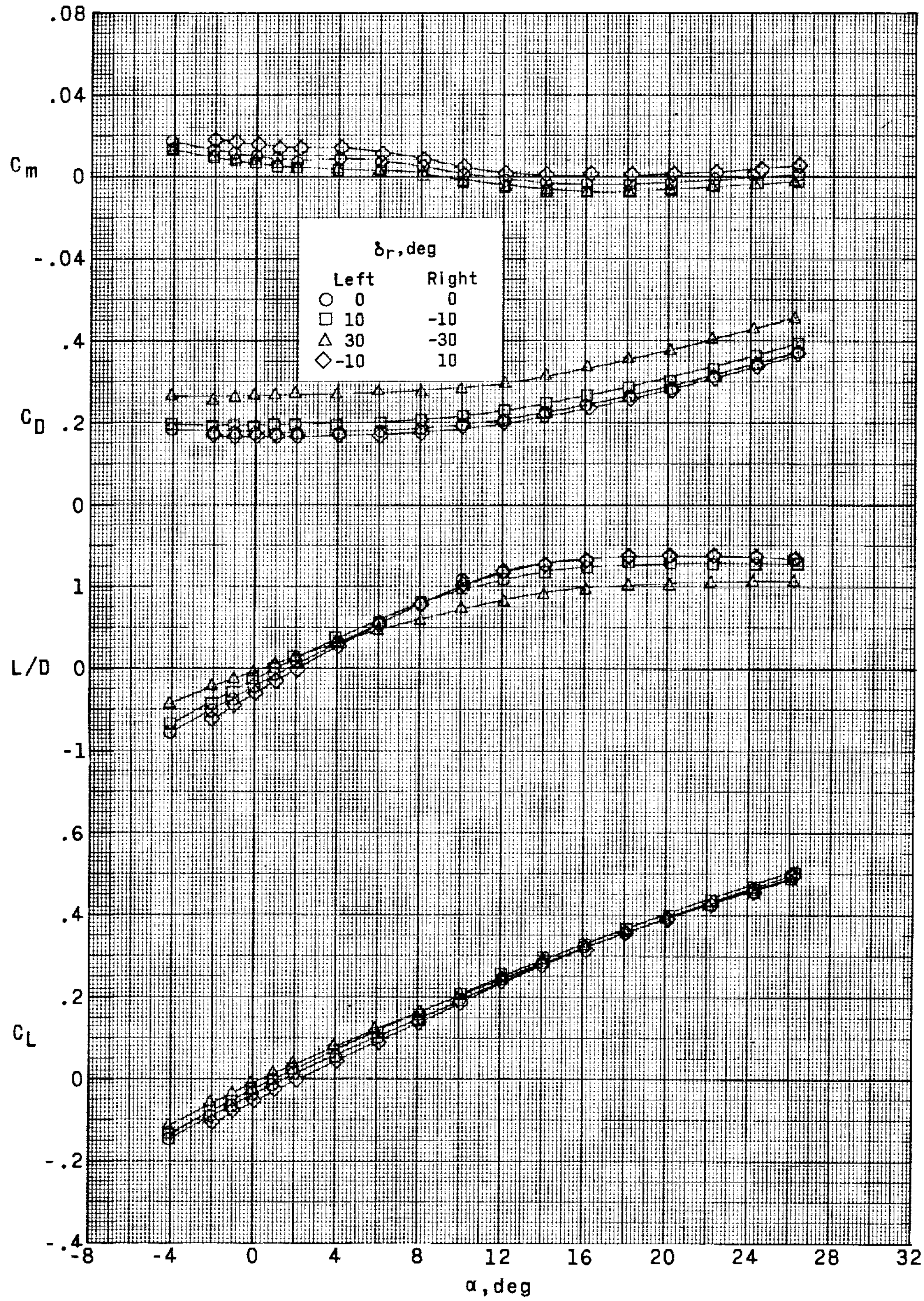


Figure 10.- Effect of toed rudders on the aerodynamic characteristics in pitch of the model; configuration $BCFF_c$; $\delta_{e_{upper}} = -30^{\circ}$; $\delta_{e_{lower}} = 0^{\circ}$.

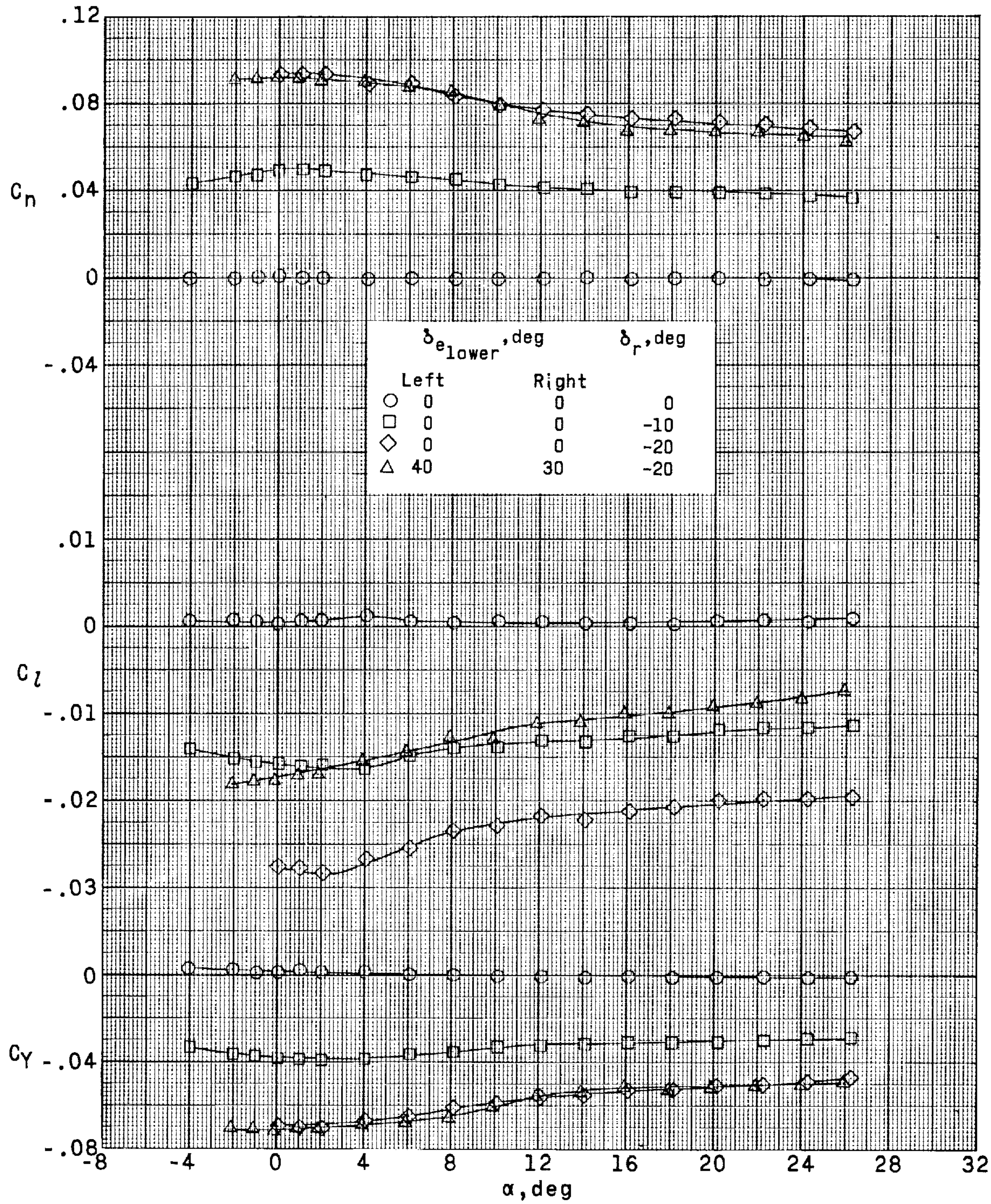


Figure 11.- Lateral aerodynamic characteristics of the model with various deflections of the rudder controls; configuration $BCFF_c$; $\delta_{e_{upper}} = -30^{\circ}$.

NASA TM X-981 THIS CARD UNCLASSIFIED
National Aeronautics and Space Administration.
STABILITY AND CONTROL CHARACTERISTICS OF A FLAT-BOTTOM LIFTING REENTRY CONFIGURATION AT A MACH NUMBER OF 1.61. H. Norman Silvers and Jerry L. Lowery. October 1964. 23p. (NASA TECHNICAL MEMORANDUM X-981) ([redacted]L)

The investigation was conducted in the Langley 4- by 4-foot supersonic pressure tunnel on a flat-bottom reentry configuration having 77° of leading-edge sweepback. The configuration was investigated with tip-mounted vertical fins, tip-mounted ventral fins, and a vertical fin in the plane of symmetry. The effect of opposite rudder deflection on the tip fins was also investigated. The investigation was made over an angle-of-attack range from about -4° to 26°.

I. Silvers, H. Norman
II. Lowery, Jerry L.
III. NASA TM X-981

GROUP 4
Downgraded [redacted] year
inter[redacted], declassified
[redacted] 12 years

THIS CARD UNCLASSIFIED

NASA

NASA TM X-981 THIS CARD UNCLASSIFIED
National Aeronautics and Space Administration.
STABILITY AND CONTROL CHARACTERISTICS OF A FLAT-BOTTOM LIFTING REENTRY CONFIGURATION AT A MACH NUMBER OF 1.61. H. Norman Silvers and Jerry L. Lowery. October 1964. 23p. (NASA TECHNICAL MEMORANDUM X-981) ([redacted])

The investigation was conducted in the Langley 4- by 4-foot supersonic pressure tunnel on a flat-bottom reentry configuration having 77° of leading-edge sweepback. The configuration was investigated with tip-mounted vertical fins, tip-mounted ventral fins, and a vertical fin in the plane of symmetry. The effect of opposite rudder deflection on the tip fins was also investigated. The investigation was made over an angle-of-attack range from about -4° to 26°.

I. Silvers, H. Norman
II. Lowery, Jerry L.
III. NASA TM X-981

GROUP 4
Downgraded a[redacted]ar
inter[redacted]classified
[redacted]2 years

THIS CARD UNCLASSIFIED

NASA

NASA TM X-981 THIS CARD UNCLASSIFIED
National Aeronautics and Space Administration.
STABILITY AND CONTROL CHARACTERISTICS OF A FLAT-BOTTOM LIFTING REENTRY CONFIGURATION AT A MACH NUMBER OF 1.61. H. Norman Silvers and Jerry L. Lowery. October 1964. 23p. (NASA TECHNICAL MEMORANDUM X-981) [redacted])

The investigation was conducted in the Langley 4- by 4-foot supersonic pressure tunnel on a flat-bottom reentry configuration having 77° of leading-edge sweepback. The configuration was investigated with tip-mounted vertical fins, tip-mounted ventral fins, and a vertical fin in the plane of symmetry. The effect of opposite rudder deflection on the tip fins was also investigated. The investigation was made over an angle-of-attack range from about -4° to 26°.

I. Silvers, H. Norman
II. Lowery, Jerry L.
III. NASA TM X-981

GROUP 4
Downgraded [redacted]ear
inter[redacted], declassified
[redacted] 12 years

THIS CARD UNCLASSIFIED

NASA

NASA TM X-981 THIS CARD UNCLASSIFIED
National Aeronautics and Space Administration.
STABILITY AND CONTROL CHARACTERISTICS OF A FLAT-BOTTOM LIFTING REENTRY CONFIGURATION AT A MACH NUMBER OF 1.61. H. Norman Silvers and Jerry L. Lowery. October 1964. 23p. (NASA TECHNICAL MEMORANDUM X-981) [redacted]

The investigation was conducted in the Langley 4- by 4-foot supersonic pressure tunnel on a flat-bottom reentry configuration having 77° of leading-edge sweepback. The configuration was investigated with tip-mounted vertical fins, tip-mounted ventral fins, and a vertical fin in the plane of symmetry. The effect of opposite rudder deflection on the tip fins was also investigated. The investigation was made over an angle-of-attack range from about -4° to 26°.

I. Silvers, H. Norman
II. Lowery, Jerry L.
III. NASA TM X-981

GROUP 4
Downgraded at [redacted]ar
intervals[redacted]assified
aft[redacted] years

THIS CARD UNCLASSIFIED

NASA

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Technical information generated in connection with a NASA contract or grant and released under NASA auspices.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

TECHNICAL REPRINTS: Information derived from NASA activities and initially published in the form of journal articles.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities but not necessarily reporting the results of individual NASA-programmed scientific efforts. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546